Investigation of Aerodynamic Performance of the NACA 0018 Airfoil at Low Reynolds Numbers: A Comparative Study of 2-D and 3-D Models Using Transition SST and k-ω SST Approaches

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Abstract:

One key challenge in modern aerodynamics is studying flows at low Reynolds numbers. Contemporary CFD tools provide advanced turbulence models for simulating such phenomena, with the γ-Re_θ model, also known as Transition SST, being a popular choice.

In this study, we calculated the NACA 0018 airfoil at 4° and 8° angles of attack, at Re=160,000. At low Reynolds numbers and below C_{Lmax}, the $C_L(\alpha)$ characteristics are nonlinear but can be approximated by two aerodynamic derivatives, $dC_L/d\alpha$. The first corresponds to low angles where laminar separation bubbles form on both sides of the airfoil, while the second relates to bubbles only on the suction side. Previously, we showed that for this airfoil and a similar Reynolds number, the boundary between these regions occurs at around 6.5° [1]. The numerical results were validated against experimental data from the literature [2].

This study created two models of a rectangular wing: 2-D and 3-D. The 3-D model represents a numerical equivalent of the wind tunnel test; however, a wall slip boundary was applied on the sidewalls, and the velocity field was computed using the Scale-Adaptive Simulation (SAS) approach.

The 3-D model was uncalibrated, while for the 2-D model, the effect of the s_1 constant, which controls laminar separation, was investigated. This paper aims to determine whether more accurate aerodynamic characteristics can be achieved through a 3-D wing model or by calibrating the turbulence model.

Figure 1 compares the pressure coefficient (Cp) distributions for 4° and 8° angles with experimental results. The 3-D model shows more irregularity due to the SAS approach. However, default turbulence settings do not improve accuracy in estimating laminar separation. Increasing the s1 constant in the Transition SST model from 2 to 3 slightly shifts the separation bubble, increasing lift and drag for AoA=8°, but reduces accuracy at AoA=4°.

Figure 2 shows the vortex structures behind the airfoils at AoA=8°, obtained using the Transition SST and k-omega SST models. Despite using the SAS model, large vortex structures are absent in the k-ω SST simulation, unlike in the Transition SST. This suggests that the k-ω SST model can be a surrogate for simulating dirty wing flow.

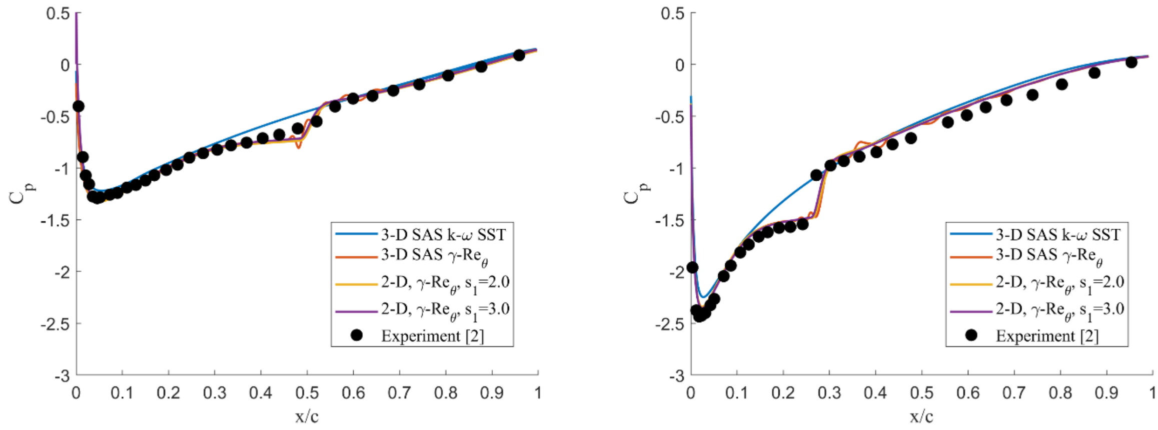

Figure 1. Pressure coefficient (Cp) distributions for the NACA0018 airfoil at two angles of attack. The left plot is for α = 4°, and the right is for α = 8°.

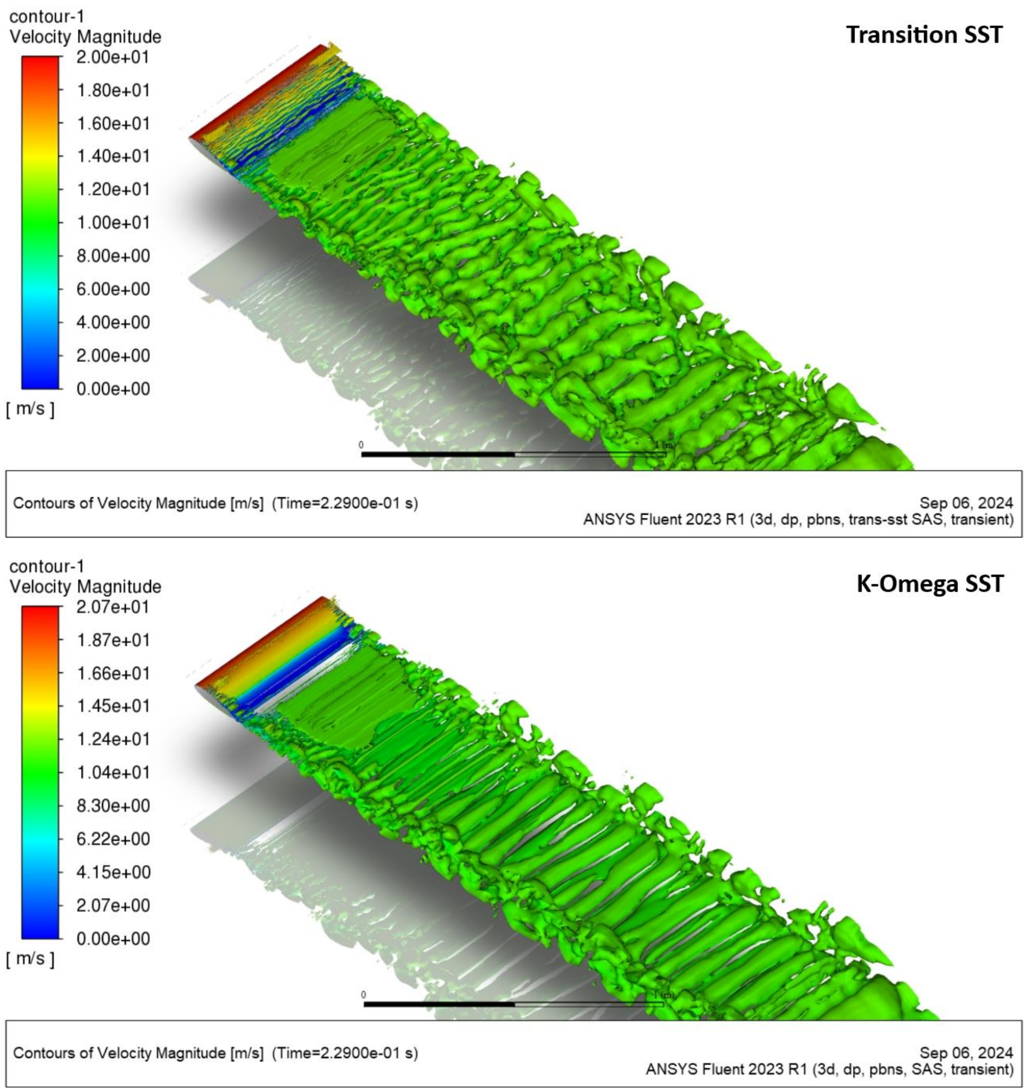

Figure 2. Velocity magnitude contours for a rectangular wing at α=8°. The top image shows results from the Transition SST model, while the bottom displays results from the k-ω SST model.

References

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2. Gerakopulos, R.; Boutilier, M.S.H.; Yarusevych, S. Aerodynamic Characterization of a NACA 0018 Airfoil at Low Reynolds Numbers. In Proceedings of the AIAA 2010-4629, 40th Fluid Dynamics Conference and Exhibit, Chicago, IL, USA, 28 June–1 July 2010.